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(71) Applicant(s)
Hazeltine Corporation

(Incorporated in USA - Delaware)

Greenlawn, New York 11740,
United States of America

(72) Inventor(s)
Jacob Sharony

(74) Agent and/or Address for Service
Andrew Walker
GEC Patent Department, Waterhouse Lane,
CHELMSFORD, Essex, CM1 2QX, United Kingdom

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(54) **Network Architecture for Linking Base Stations**

(57) A backbone network architecture links base stations of a cellular wireless communication system. A number N of base stations is arranged such that each base station serves a corresponding cell in a cellular wireless communication system. Each base station is assigned a different address word of length D, wherein each letter of the address word is a digit in base-m such that $N = m^D$, and a given base station is linked for direct communication with other base stations which have an assigned address that differs by only one digit with respect to the address assigned to the given base station. Each set of base stations linked for direct communication with one another defines a different subnet of the communication system, permitting the efficient routing of multicast and broadcast types of information throughout the system.

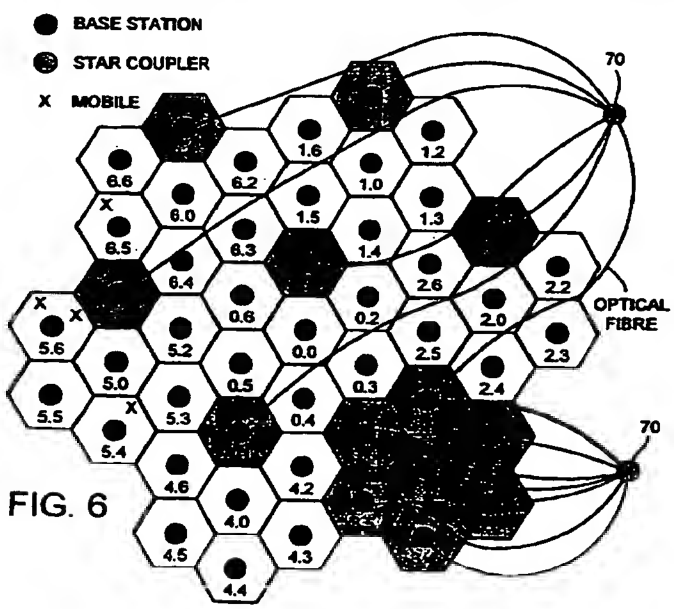

FIG. 6

A 49-NODE SB(7,2) NETWORK (N=49, m=7, D=2).

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

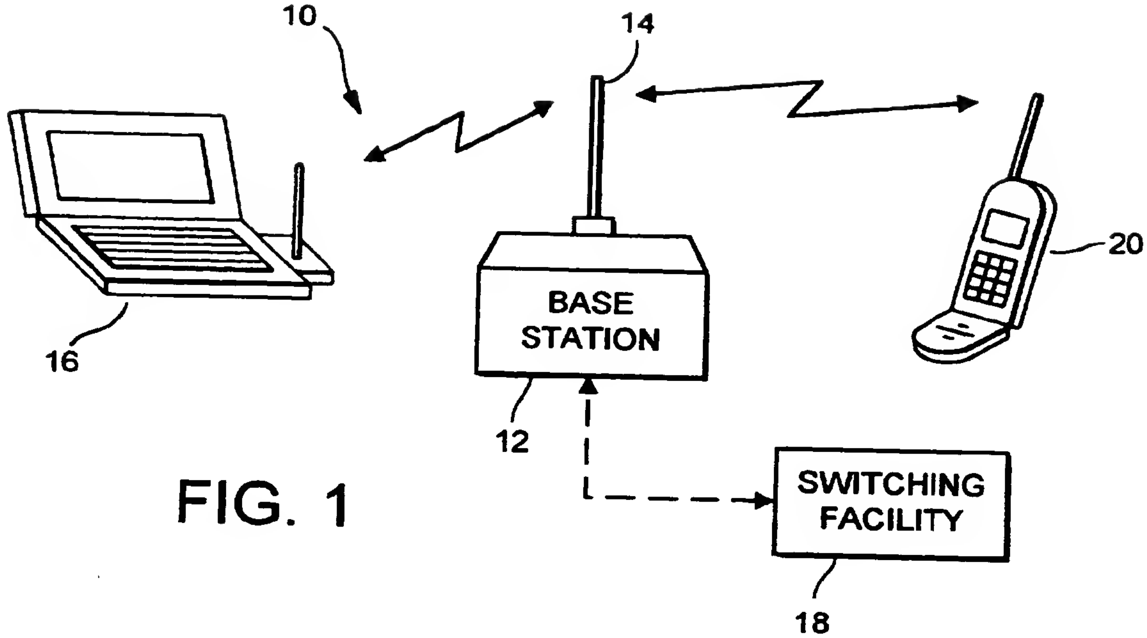

10
14
BASE
STATION
20
16
12
SWITCHING
FACILITY
18

FIG. 1

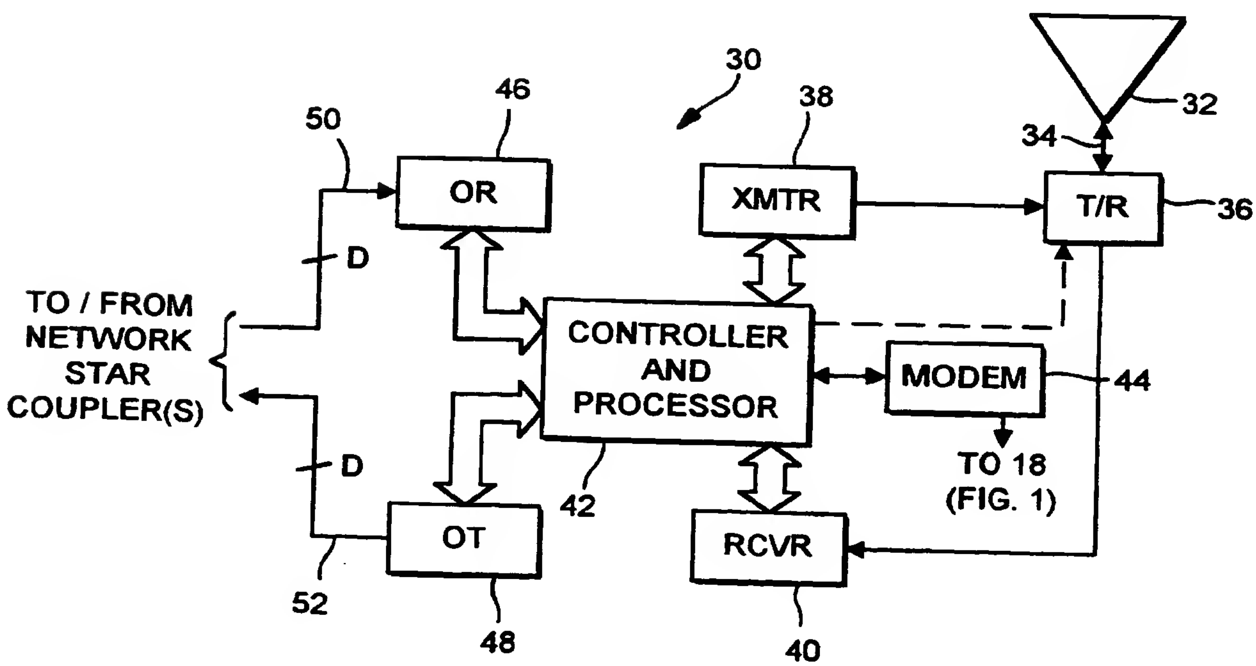

30
46
38
32
50
34
OR
XMTR
T/R
36
D
TO / FROM
NETWORK
STAR
COUPLER(S)
CONTROLLER
AND
PROCESSOR
MODEM
44
D
TO 18
(FIG. 1)
42
OT
RCVR
52
48
40

FIG. 2

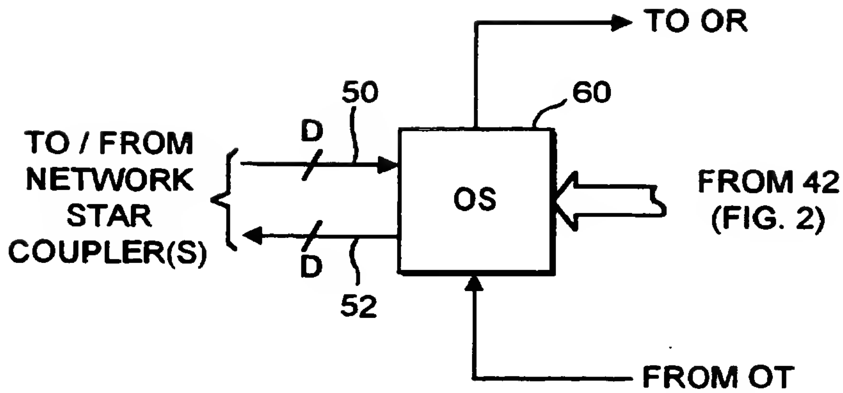

TO OR
50
60
D
TO / FROM
NETWORK
STAR
COUPLER(S)
OS
FROM 42
(FIG. 2)
D
52
FROM OT

FIG. 3

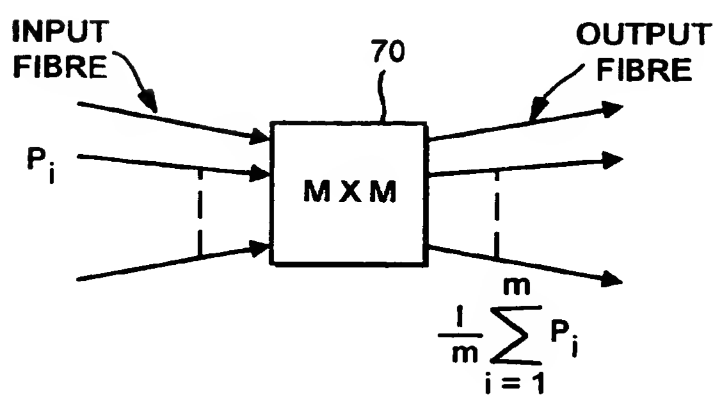

INPUT
FIBRE
70
OUTPUT
FIBRE
P_i
M X M
$\frac{1}{m}\sum_{i=1}^{m} P_i$

FIG. 4

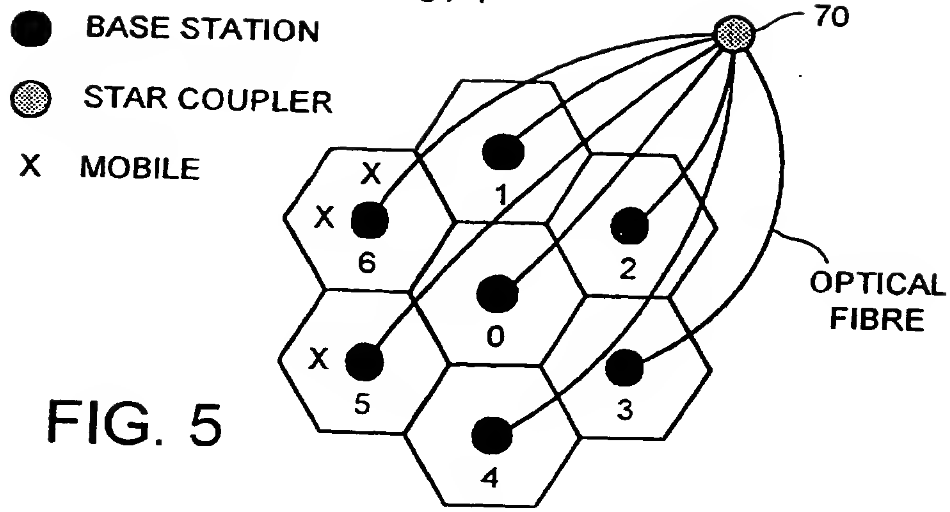


FIG. 5

A 7-NODE SB(7,1) NETWORK (N=7, m=7, D=1).

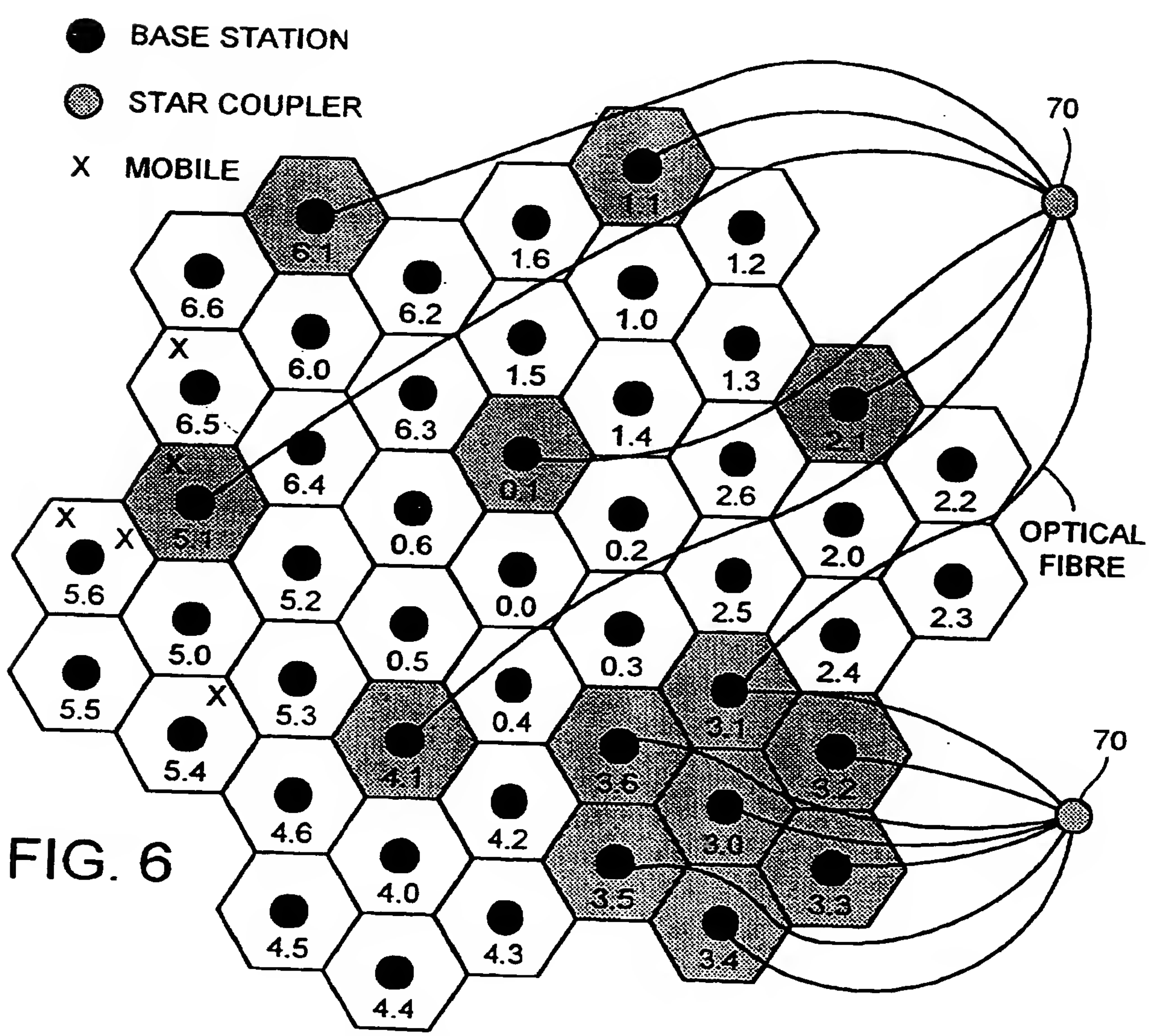
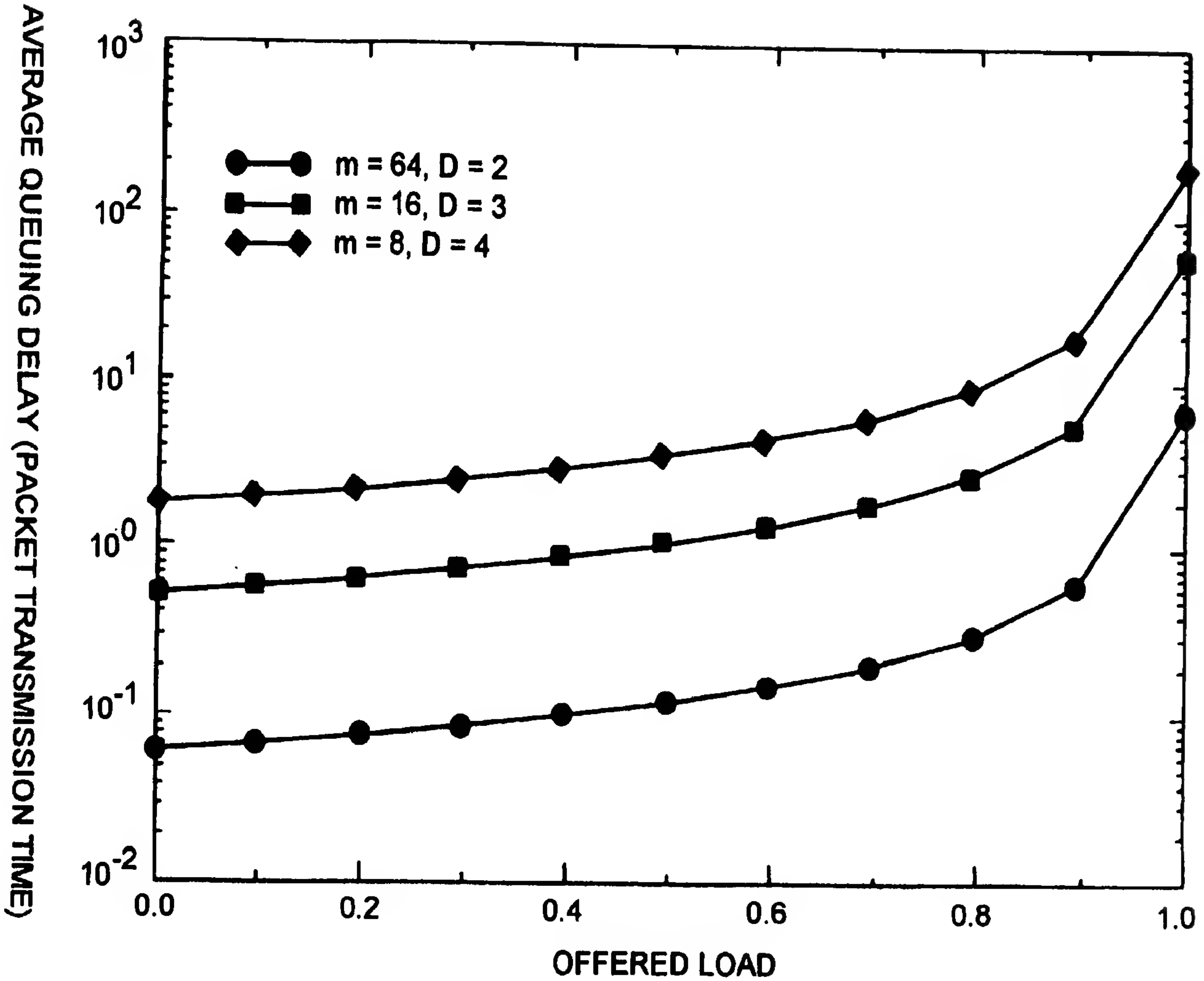


FIG. 6

A 49-NODE SB(7,2) NETWORK (N=49, m=7, D=2).



NORMALIZED AVERAGE PACKET QUEUING DELAY - $\mu R\delta_{av}$ vs. NOMALIZED USER OFFERED LOAD - P FOR A 4096 - NODE NETWORK FOR DIFFERENT VALUES OF SUBNET - SIZE - m AND DIAMETER - D

FIG. 7

COMMUNICATION SYSTEMS

The present invention relates generally to cellular wireless communication systems, and particularly to a backbone network architecture that interconnects system base stations with one another in a highly efficient and fault-tolerant manner.

Because of increasing demand for mobile services and rapid changes in key technologies, cellular wireless communication systems are growing at a fast pace. Conventional cellular systems have three basic elements, namely, at least one mobile station, a base station and a central switching facility. As used herein, "mobile station" refers to a portable unit (telephone, computer) which can be either stationary or moving. The base station refers to a fixed installation which serves mobile stations in its vicinity or "cell" via a suitable antenna array, by exchanging wireless communications using radio signals. The base stations are connected together to the central switching facility by a so-called backbone network, which can be wired or wireless. The central switching facility connects the base stations with a service provider, e.g., a telephone company, through the backbone network. Functions of the switching facility include frequency channel assignment, "handing off" a mobile user from one base station to another as the user moves into another base station cell, monitoring, and billing.

Next generation cellular communication systems will be expected to support multimedia services for mobile users, thus creating a need for an efficient backbone network architecture to link base stations of the future systems with one another. The network architecture should be capable of supporting broadcast or point-to-multipoint

communication links. Preferably, the architecture should permit a self-contained communication system that can serve a specific area, for example, inside of a building or an entire building campus, without connection to a backbone service provider such as a telephone company.

An object of the invention is to provide a scalable network architecture having low complexity.

According to the invention, a method of configuring a backbone network architecture for interconnecting base stations in a cellular wireless communication system, comprises arranging a number N of base stations such that each base station serves a corresponding cell in a cellular wireless communication system, and assigning each base station a different address word of length D, wherein each letter of said address word is a digit in base-m such that $N = m^D$. A given base station is linked for direct communication with other base stations which have an assigned address that differs by only one digit with respect to the address assigned to the given base station, and each group of base stations linked for direct communication with one another defines a different subnet of the communication system.

An embodiment of the invention will now be described by way of example only in which:

FIG. 1 is a representation of a cell in a cellular wireless communication system;

FIG. 2 is a schematic block diagram of a system base station configured according to the invention;

FIG. 3 is a schematic diagram of an optical switch arrangement;

FIG. 4 is a schematic diagram of an optical star coupler;

FIG. 5 is a representation of an area subnet according to the invention;

FIG. 6 is a representation of a two-level backbone network according to the invention; and

FIG. 7 is a graph depicting average packet queuing delay as a function of offered load in the present backbone network.

FIG. 1 shows one cell 10 of a cellular wireless communication system. The cell 10 includes a base station 12 with an antenna array 14 that enables the base station to communicate with mobile users in the cell served by the base station 12. For example, a user can link a portable computer 16 with a data base or other computer through a wireless link between the computer 16 and base station 12, and through a wire link between the base station and a central switching facility 18. The facility 18 is usually capable of providing data communication using a public switched telephone network (PSTN). Similarly, a user of a portable telephone 20 within the cell served by the base station 12 may wish to place a call via a wireless link with the base station 12, and the wire link between the central switching facility 18 and the base station. The overall

communication system includes a number of other base stations similar to base station 12. In a "self contained" system, a number of the base stations 12 are inter-connected with one another, and the central switching facility 18 is omitted.

The present invention may be applied in any cellular system having base station cells such as the cell 10 in FIG. 1, including systems where the base stations cover relatively small areas known as "microcells" and have no links with outside switching facilities, i.e., stand alone or self-contained systems. It is contemplated that all of the system base stations are linked with one another through a wired backbone network, as described below.

FIG. 2 is a schematic block diagram of a base station 30, configured according to the invention. Base station 30 has an antenna 32 that is coupled through a transmission line 34 with an antenna switch 36. One or more radio frequency (RF) transmitters 38, and one or more RF receivers 40 are coupled to corresponding ports of the switch. As is known in the art, having multiple transmitters 38 and receivers 40 enables wireless communication with a number of users in the base station cell (or microcell) simultaneously. The transmitter(s) 38, receiver(s) 40, and other equipment in the base station 30, are under the control of a controller and processor unit (hereafter "controller") 42. The controller 42 typically includes working memory and storage memory areas, and such input/output (I/O) circuitry that is necessary to interface the controller 42 with operating components of the base station 30, the central switching facility 18 (if used in the system), and other system base stations. Communications between the base station 30 and the outside switching facility 18 (if provided) may be implemented through a modem 44. In a self-contained system, the modem 44 would be unnecessary.

Communication links between the base station 30 and other base stations of the system are enabled by optical receivers (OR) 46 and optical transmitters (OT) 48, which together couple the base station 30 with other system base stations through an optical backbone network with which the ORs 46 and the OTs 48 are connected by fibre optic cables 50, 52. For base stations in which only one optical transmitter and receiver (transceiver) are provided, an optical switch (OS) 60 may be arranged as shown in FIG. 3, to interface the input/output fibre cables 50, 52 with the base station optical transceiver.

In the illustrated embodiment, the backbone network comprises a number of star couplers 70, one of which is represented in FIG. 4. Each coupler 70 has m input fibres and m output fibres. Any signal applied to one input fibre of a coupler is uniformly power-divided and distributed among all of the output fibres of the same coupler. The configuration of the present backbone network is described further below.

The remaining disclosure is organized as follows:

A. Addressing Method
B. Network Architecture
C. Routing
D. Performance

A. Addressing Method

The present backbone network has a topology that is defined by an alphabet of size m

containing the numbers 0,1,2,...m-1, wherein each base station in the network is assigned a word of length D, and each letter is a digit in base-m (e.g., if $m = 4$ and $D = 3$, base station 62 is represented by 3.3.2). Therefore, the total number of words (base stations) possible is $N = m^D$. According to the invention, each base station is linked for direct communication with every other base station in the network whose assigned address, in the mentioned topology, differs by exactly one digit. That is, $\forall i$, base station $x_{D-1}x_{D-2}...x_i...x_1x_0$ is connected to base station $x_{D-1}x_{D-2}...x'_i...x_1x_0$, $0 \leq x'_i \leq m-1$, $x'_i \neq x_i$. Thus, each base station is connected to D(m-1) other base stations, such that each base station has D(m-1) "logical neighbours". Next, we group every m base stations that differ in one digit, i.e., group (subnet) k contains all base stations $x_{D-1}x_{D-2}...x_K...x_1x_0$, $0 \leq x_k \leq m-1$ (which differ in digit k). Note that each base station is a member of D other groups. It can be shown that there are Dm^{D-1} such groups. These groups (subnets) are the basic building blocks of the present backbone network.

B. Network Architecture

The overall communication system architecture includes a fixed wired segment in the form of an the optical backbone network that connects all the base stations with one another, and a wireless segment connecting mobile users with the base stations. In B.1, below, the optical backbone network is described. In B.2, the wireless segment is discussed.

B.1 Optical Backbone Network

In the present backbone network architecture, referred to as Star-Base (SB), system base stations are grouped into subnets of size m, where each base station is affiliated with D subnets. The base stations in each subnet are connected together by an m x m broadcast star, or star coupler 70, with two fibres (in/out) per base station. Each base station accesses its subnets using, for example, a single optical transceiver tunable over m wavelength channels, wherein a time-sharing scheme may be employed to access the different subnets. The optical switch 60 would be included as in FIG. 3, and a time frame of D slots may be used with one slot for each subnet. For example, in the first slot, a given base station may communicate in its own area subnet of m base stations, which stations differ in their assigned addresses by only the least significant digit.

A time multiplex scheme can be avoided by providing D optical transceivers per base station as in FIG. 2. Each tunable transceiver comprises a tunable optical transmitter, a tunable optical receiver, or both. Note that the m wavelengths are reused in every subnet. Within each subnet, the m base stations can use one of several known wavelength division multiple access (WDMA) protocols described, for example, in B. Mukherjee, "WDM Based Local Lightwave Networks Part I", IEEE Network, vol. 6 as 12-27 (May 1992).

B.1.1 Construction

The following example describes a backbone network beginning with a lowest order subnet (a single-hop m-node network), and higher. FIG. 5 depicts a 7-node SB(7,1) network, showing seven base stations of a given area subnet connected together directly by an optical star coupler. FIG. 6 shows a 49-node SB(7,2) network built from seven

of the 7-node SB(7,1) networks. In the backbone network of FIG. 6, each base station is affiliated with two subnets each containing seven base stations. For example, see base station 3.1 and its logical neighbours in the areas shaded in FIG. 6, which shows a two-level backbone network. Base station 3.1 is linked via a star coupler 70 for direct communication with the other base stations 3.x ($x \neq 1$) in area subnet 3. The base station 3.1 is also linked via another star coupler 70 for direct communication with corresponding affiliated base stations x.1 ($x \neq 3$) in the other area subnets. In general, a SB(m,D) network is constructed from preferably m copies of a SB(m,D-1) network, by connecting those base stations having the same address in the SB(m,D-1) network for direct communication through a common star coupler in the constructed SB(m,D) network.

B.1.2 Complexity

Define "complexity" of the backbone network as a count of basic active switching elements (see J. Sharony, et al, "The Universality of Multi-Dimensional Switching Networks, IEEE/ACM Transactions on Networking, vol. 2, No. 6 (Dec. 1994)). Assume that each node has D transceivers, one for each subnet it is affiliated with. Further, assume that each transceiver has a fixed-tuned transmitter (tuned to a specific wavelength), and a tunable receiver (over m distinct wave-lengths). Note that by definition, passive elements such as star couplers are not included in the complexity, since active elements usually dominate the cost of a given system.

Per J. Sharony, et al, id, the complexity of each tunable receiver (the only active element in the network) is proportional to m, thus, the complexity of the network is proportional

to mDN or $DN^{1+1/D}$, which makes the present architecture scalable. For example, suppose that the diameter of the network is D = 3; then the complexity is proportional to $3N^{4/3}$.

B.2 Wireless Network

The mobile stations or users are linked to the backbone network via the base stations, using, for example, wideband radio links. Each base station 12 serves mobile users in its own microcell 10. Each mobile user has an address that depends on its location, and which is defined by the address of the base station which currently serves it. Accordingly, when a mobile user changes its location, it acquires a new address corresponding to its current base station.

B.2.1 Location updating

Each base station of the overall communication system is aware of those mobile users in its microcell, which users are currently served by the base station. When a mobile user moves to a new location, its current base station updates other base stations about the mobile user's new address. Each base station notifies its logical neighbours, i.e., those base stations with which it is linked through two or more star couplers, of all the mobile users in its microcell. It can be shown that for D = 2, a base station can locate any mobile user served by another base station, by inquiring at its logical neighbours. That is, at least one of its logical neighbours knows the location of the mobile user. In general, for D > 2, the locating process involves inquiries beyond the logical neighbours. It can be shown that the inquiry can be completed in D - 1 steps, i.e., D - 2 steps beyond

the logical neighbours.

B.2.2 Handoffs

When a mobile user moves between microcells, the data forwarded to its original base station should be re-routed to its new base station in its new microcell. This process of data re-routing is referred to as handoff or handover. To support time sensitive multimedia services such as audio and video, disruption in data flow due to handoffs should be minimized to meet time deadlines required for real-time data. That is, handoff delays should be kept to a minimum.

Therefore, the source base station preferably multicasts data associated with a specific mobile user to the base station currently serving the user, and its adjacent base stations (to which the user is next likely to move). Thus, when handoff occurs, the routing of the data to the new microcell has already been performed. This allows a mobile user to continue to receive data immediately after moving to a new microcell. It can be shown that the multicast operation can be completed in not more than D rounds (see C.1 below) for any size network.

Referring to FIG. 6, assume that the source and the destination base stations are 6.0 and 3.1, respectively. The data intended for a mobile user served by base station 3.1 is multicasted to base stations 3.1, 2.5, 2.4, 3.2, 3.0, 3.6 and 0.3. Assume that later, the mobile user moves to another microcell served by base station 2.5. Source base station 6.0 will then multicast the data to destination base stations 2.5, 2.6, 2.0, 2.4, 3.1, 0.3 and 0.2.

C. Routing

Several routing schemes are possible. A so-called shortest-path routing procedure is described, which is self-routing. In this procedure, routes traverse base stations having addresses that differ one digit at a time in a fixed order, e.g., from the least significant digit to the highest. Consider the following example for the 49-node network in FIG. 6. Suppose the source base station is 0.0 and the destination base station is 2.3. A routing algorithm would use the path 0.0 → 0.3 → 2.3. In general, the route from source base station $u_{D-1}u_{D-2}...u_1u_0$ to destination base station $v_{D-1}v_{D-2}...v_1v_0$, would traverse the path $u_{D-1}u_{D-2}...u_1u_0 \rightarrow u_{D-1}u_{D-2}...u_1v_0 \rightarrow u_{D-1}u_{D-2}...u_2v_1v_0 \rightarrow ...$
$\rightarrow u_{D-1}v_{D-2}...v_1v_0 \rightarrow v_{D-1}v_{D-2}...v_1v_0$.

The length of the path equals the number of different digits in the addresses of the source and the destination base stations. In the above procedure, there is a unique path between any two base stations.

Another self-routing scheme, referred to as Long-path routing, results in high fault-tolerance (see D.4 below). In this procedure, the longest path has D + 1 hops. The source base station selects (e.g., randomly) a logical neighbour (e.g., in subnet i) from which point a shortest-path routing procedure is used traversing consecutively one digit at a time starting with digit (i+1)mod D (via subnet (i+1)mod D), and finishing at digit i (in subnet i) after traversing D digits in a cyclic mode. In general, the route from source base station $u_{D-1}u_{D-2}...u_1u_0$ to destination base station $v_{D-1}v_{D-2}...v_1v_0$, would traverse the path

$$u_{D-1}u_{D-2}\ldots u_i\ldots u_1u_0 \rightarrow u_{D-1}u_{D-2}\ldots u_i'\ldots u_1u_0 \rightarrow u_{D-1}u_{D-2}\ldots v_{i+1}u_i'\ldots u_1u_0 \rightarrow$$

$$u_{D-1}u_{D-2}\ldots v_{i+2}v_{i+1}u_i'\ldots u_1u_0 \rightarrow \ldots \rightarrow u_{D-1}v_{D-2}\ldots v_{i+1}u_i'\ldots u_1u_0 \rightarrow$$

$$v_{D-1}v_{D-2}\ldots v_{i+1}u_i'\ldots u_1u_0 \rightarrow v_{D-1}v_{D-2}\ldots v_{i+1}u_1'\ldots u_1v_0 \rightarrow$$

$$v_{D-1}v_{D-2}\ldots v_{i+1}u_i'\ldots v_1v_0 \rightarrow \ldots \rightarrow v_{D-1}v_{D-2}\ldots v_{i+1}u_1'v_{i-1}\ldots v_1v_0 \rightarrow$$

$$v_{D-1}v_{D-2}\ldots v_{i+1}v_iv_{i-1}\ldots v_1v_0$$

where $0 \leq i \leq D-1$, and $u'_i \neq u_i$.

It can be shown that between each source-destination pair of base stations, there are D(m-1) disjoint paths, i.e., paths that do not share nodes. Each of these paths corresponds to one of the D(m-1) logical neighbours of the source base station. Note that a path is uniquely specified once a logical neighbour is selected by the source base station. To route a packet from a source base station to a destination base station, the source base station selects (e.g., at random) one of the D(m-1) disjoint paths. In case of a path failure, the source base station can select one of the remaining disjoint paths. Note that if no more than D hops per path are allowed, there are only D node-disjoint paths (instead of D(m-1)) between any source-destination pair.

C.1 Multicast Broadcast

Broadcast or multicast operation can be completed in at most D rounds, regardless of the backbone network size. This implies that communication time needed to broadcast (multicast) a packet depends only on the diameter and not on network or subnet size. To broadcast a packet from source base station $u_{D-1}u_{D-2}\ldots u_1u_0$ to all the other base stations in the network, the following distribution steps can be used, where each

distribution step corresponds to a multicast-tree containing the source base station (root) and all the base stations which so far have received the packet.

$$u_{D-1}u_{D-2}\ldots u_i\ldots u_1u_0 \rightarrow x_{D-1}u_{D-2}\ldots u_i\ldots u_1u_0 \rightarrow$$
$$x_{D-1}x_{D-2}\ldots u_i\ldots u_1u_0 \rightarrow \ldots \rightarrow x_{D-1}x_{D-2}\ldots x_i\ldots u_1u_0 \rightarrow \ldots \rightarrow$$
$$x_{D-1}x_{D-2}\ldots x_i\ldots x_1u_0 \rightarrow x_{D-1}x_{D-2}\ldots x_i\ldots x_1x_0$$

where $0 \leq x_k \leq m - 1, 0 \leq k \leq D - 1$.

D. Performance

Network performance in terms of average number of hops, subnet load, delay, throughput and fault-tolerance, are now evaluated. It is assumed that the mentioned shortest path routing, is used.

D.1 Average Number of Hops

The average number of hops h for the present SB network can be found by averaging the total number of hops over all the possible N(N-1) paths (from any base station to any base station). Since the network is symmetric, it is sufficient to consider only N - 1 paths from a given base station to all the other base stations. Taking into account the fact that the distance (number of hops) between any two base stations equals the number of different digits between their labels (e.g., 1.2.2, and 2.1.2, are 2 hops away), one finds that the average number of hops is given by:

$$\bar{h} = \frac{1}{N-1} \sum_{i=1}^{D} i \binom{D}{i} (m-1)^i \tag{1}$$

using the equality

$$\sum_{i=1}^{D} \binom{D-1}{i-1} (m-1)^{i-1} = m^{D-1} \tag{2}$$

(1) becomes

$$\bar{h} = \frac{m-1}{m} \frac{N}{N-1} D \tag{3}$$

TABLE 1, below, shows the average number of hops $\bar{h}$ for different values of subnet size m and diameter D for the Star-Base with a total number N of base stations in the network. Note that by definition (using shortest-path routing), $\bar{h}$ is the minimal average number of hops possible in the defined networks.

TABLE 1

m,D	N	$\bar{h}$
4,2	16	1.60
4,3	64	2.29
4,4	256	3.01
8,2	64	1.78
8,3	512	2.63
8,4	4,096	3.50
16,2	256	1.88
16,3	4,096	2.81
16,4	65,536	3.75
32,2	1,024	1.94
32,3	32,768	2.91
32,4	1,048,576	3.88

D.2 Subnet Load

Subnet load is defined as the number of times a given subnet is traversed by all possible N(N - 1) paths of source-destination pairs. In general, the average subnet load η_{av} is related to the average number of hops $\bar{h}$ through the following relation:

$$S\eta_{av} = N\ (N-1)\ \bar{h} \tag{4}$$

where S is the number of subnets in the network,

$$S = Dm^{D-1} = DN/m \tag{5}$$

Substituting eq. (3) and eq. (5) into eq. (4), the average subnet load is given by

$$\eta_{av} = N\ (m-1) \tag{6}$$

To find the maximum subnet load η_{max}, define P_k as the maximum number of paths of length $k(1 \leq k \leq D)$ that use any given subnet. It can be shown that for the proposed network

$$P_k = \binom{D-1}{k-1}\ m(m-1)^k \tag{7}$$

Therefore,

$$\eta_{max} = \sum_{k=1}^{D} P_k = m^D\ (m-1) = N\ (m-1) \tag{8}$$

Note that the maximum subnet load η_{max} equals the average subnet load η_{av}. Thus, all the subnets in the network have the same load. This means that for any other routing

scheme $\eta_{max} \geq N(m-1)$. Therefore, the current routing procedure achieves maximum throughput and minimum delay for all loads, from zero up to when the maximum throughput is achieved.

D.3 Delay and Throughput

Assume an M/M/1 queuing model to describe a single subnet behavior, and that each base station is equally likely to communicate with all of the other base stations. For each source-destination pair, let λ be the mean arrival rate of packets/sec at the source base station. Thus, the total arrival rate of packets for the subnet k is $\eta_k\lambda$, where η_k is the subnet load, and the average queuing delay for a packet at subnet k is given by

$$\delta_k = \frac{1}{\mu C_k - \eta_k \lambda}$$

where $1/\mu$ is the average packet length in bits and C_k is the subnet capacity in bits/sec. Note that if a more accurate model for subnet behavior is used, it will only yield a different expression for δ_k. Using Little's formula (see M. Schwartz, Telecommunication Networks, Protocols, Modeling and Analysis (1987), at page 41) the total average queuing delay for a packet across the network is given by

$$\delta_{av} = \frac{1}{\Lambda} \sum_{k=1}^{S} \frac{\eta_k \lambda}{\mu C_k - \eta_k \lambda} \tag{9}$$

where Λ is the offered traffic in the network. Note that $\Lambda = N(N-1)\lambda$. Assuming a single transceiver per base station (tunable over m wavelengths and time-shared in D subnets) using a bandwidth R bits/sec., all subnets have the same capacity of $C_k = mR/D$. Substituting the above values into eq.(9), the average queuing delay across the network is given by

$$\delta_{av} = \frac{1}{N(N-1)} \sum_{k=1}^{DN/m} \frac{N(m-1)}{\mu mR/D - N(m-1)\lambda} \qquad (10)$$

or

$$\delta\, av = \frac{\frac{m-1}{m}\frac{N}{N-1}D}{\mu mR/D - N(m-1)\lambda} = \frac{\bar{h}}{\mu mR/D - N(m-1)\lambda} \qquad (11)$$

where the maximum value of λ is

$$\lambda_{max} = \frac{\mu mR}{DN(m-1)} \qquad (12)$$

Substituting eq.(12) into eq. (11), and after some arrangements, one obtains

$$\mu R\delta_{av} = \frac{\bar{h}D}{m}\frac{1}{1-\frac{\lambda}{\lambda_{max}}} \qquad (13)$$

The offered load per user is given by

$$\gamma = (N-1)\lambda \qquad (14)$$

and the user throughput is defined as the maximum user offered load for which the delay is finite, i.e.,

$$\Gamma = (N-1)\lambda_{max} \tag{15}$$

Define the normalized offered load per user by

$$\rho \equiv \frac{\gamma}{\Gamma} = \frac{\lambda}{\lambda_{max}} \tag{16}$$

and eq. (13) becomes

$$\mu R \delta_{av} = \frac{\bar{h}D}{m}\frac{1}{1-\rho} \tag{17}$$

Note that the left side of eq. (17) is the average packet queuing delay across a network in units of packet transmission time.

FIG. 7 depicts the normalized average packet queuing delay $\mu R\delta_{av}$ as a function of normalized user offered load, for a 4096 base station backbone network and for different values of subnet-size m and diameter D. It is assumed that each base station has a single tunable transceiver over m distinct wavelength-channels. Observe the increase in delay for networks with smaller subnets and larger diameters.

D.4 Fault-tolerance

The fault-tolerance of the present backbone network architecture is evaluated using two metrics, namely "node-connectivity" and "path-connectivity". Define node-connectivity - κ as the minimum number of faulty nodes that creates a disconnected network. Since each base station in the Star-Base is connected directly to D(m-1) other base stations,

the connectivity of the network is $\kappa = D(m-1)$. For example, consider a 256-node (base station) network with diameter $D = 2$ having area subnets of 16 base stations each. Any 29 base stations can be faulty before the network becomes disconnected.

Define the network "path-connectivity" - σ as the minimum number of node-disjoint paths between any source-destination pair (i.e., paths that do not pass through the same node). The path-connectivity of the topology is $\sigma = D$ for path-lengths of not more than D hops. If we allow path-lengths to be up to D+1 hops (using Long-path routing), it can be shown that the path-connectivity reaches its maximum value of $\sigma = D(m-1)$. Referring to the above example, there are at least 30 node-disjoint paths, i.e., alternative paths between any source-destination pair with path-lengths of at most three hops. Since the network has high node-connectivity and high path-connectivity, it is very reliable.

The foregoing describes a backbone network architecture, particularly an optical backbone network, that is especially suitable for interconnecting base stations with one another in a distributed micro-cellular wireless communication system. In the present architecture, base stations are grouped into one-hop subnets each of size m, and are interconnected with one another through m x m star couplers. The network can support $N = m^D$ base stations, where D is the network diameter (typically 2, 3). Each base station is affiliated with D subnets, and has an optical transceiver(s) tunable over m distinct wavelength channels. The multicast nature of the architecture lends itself to fast routing and mobility control schemes supporting point-to-multipoint connections. The network is highly fault-tolerant, operates in a self-routing mode, and exhibits a near balanced load resulting in high throughput and low delay.

Star couplers 70 as disclosed and described in connection with FIG. 4, or equivalent means, are preferred for linking the system base stations for direct communication with other selected base stations because of the ability of the coupler 70 to broadcast information simultaneously from a single base station to other base stations linked to the coupler. This "point-to-multipoint" feature is desirable for communicating important system information rapidly, such as the location (or address) of a mobile user as the user moves from one cell to another within the system, and other multicast or broadcast types of communications generally.

Passive routers, which perform point-to-point connections wherein an output port is uniquely defined by an input port and the wavelength of a signal at the input port, may be substituted for the star couplers 70. Such substitution will, however, reduce the system efficiency for multicast types of sessions, and when communicating common signalling and system control information to all base stations of the system.

CLAIMS

1. A method of configuring a backbone network architecture for interconnecting base stations in a cellular wireless communication system, comprising:
arranging a number N of base stations such that each base station serves a corresponding cell in a cellular wireless communication system;
assigning each base station a different address word of length D, wherein each letter of the address word is a digit in base-m such that $N = m^D$; and
linking a given base station for direct communication with other base stations which have an assigned address that differs by only one digit with respect to the address assigned to the given base station;
in which each group of base stations linked for direct communication with one another defines a different subnet of the communication system.

2. A method according to claim 1, in which linking for direct communication is carried out with optical star coupler means.

3. A method according to claim 1 or claim 2, in which each of said subnets is formed with an equal number of said base stations.

4. A method according to any preceding claim, in which each defined subnet is allocated a different time slot during which the base stations that are linked to define the subnet communicate directly with one another.

5. A method according to any preceding claim, in which information from a source

base station is routed to a destination base station by traversing base stations having addresses that differ one digit at a time in a fixed order.

6. A method according to any one of claims 1 to 4, in which information from a source base station is routed to a destination base station by selecting a logical neighbour of the source base station, and traversing, from the logical neighbour, base stations having addresses that differ one digit at a time consecutively.

7. A cellular wireless communication system, comprising:

a number of base stations each having transmitter/receiver means for wireless communication with users located in corresponding cells served by the base stations, and controller means for controlling operations at each base station;

each of the base stations being identifiable by a different address word of length D, wherein each letter of said address word is a digit in base-m such that $N = m^D$; and

backbone network means for establishing communication links between each of said base stations, said network means including means for linking a given base station for direct communication with other base stations which have an assigned address that differs by only one digit with respect to the address assigned to the given base station;

in which each group of base stations linked for direct communication with one another defines a different subnet of the communication system.

8. A cellular wireless communication system according to claim 7, in which the linking means comprises a number of optical star couplers.

9. A cellular wireless communication system according to claim 7 or claim 8, in which each of the subnets has an equal number of base stations.

10. A cellular wireless communication system according to any of claims 7 to 9, in which the controller means of each base station has means for allocating each defined subnet a different time slot, during which time slot the base stations that are linked to define the subnet communicate directly with one another.

11. A cellular wireless communication system according to any of claims 7 to 10, in which the controller means of each base station has means for routing information from a source base station to a destination base station by traversing base stations having addresses that differ one digit at a time in a fixed order.

12. A cellular wireless communication system according to any of claims 7 to 10, in which the controller means of each base station has means for routing information from a source base station to a destination base station by selecting a logical neighbour of the source base station, and traversing, from the logical neighbour, base stations having addresses that differ one digit at a time consecutively.

The Patent Office

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Claims searched:	all	**Date of search:**	11 March 1998

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Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.P): H4L (LDSG, LDSL, LDSY)

Int Cl (Ed.6): H04Q 7/22,7/36,7/38

Other: Online: WPI, INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
	NONE	

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